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IMPROVED BRIGHTNESS OF THE ATA INJECTOR

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Introduction

Studies of the ATA injector using the low density plasma cathode (flashboard cathode) have shown that the brightness of the injector was being limited by the non-uniform emission of the cathode surface.[1] To avoid this difficulty, we rearranged the cathode-anode geometry to accommodate field shaping surfaces and a field emission cathode.

Computer simulations of the cathode-anode geometry using the EBQ code led us to try a 5.5 cm radius cathode with an A-K gap of about 13 cm. There was no grid used during the experiment. The cathode was surrounded by a Pierce correcting shroud and the typical gap voltage was about 2.5 MeV. Our initial tests of the field emission cathodes were done using a woven carbon yarn that was laced through a fine mesh screen and then trimmed to a uniform height. Using these "tufted" cathodes, it was easy to vary the number of emission sites per square centimeter. We also varied the geometry of these cathodes by giving the screen a slight convex shape so that the center of the cathode was about 1 cm closer to the anode plane than the edge of the cathode.

At the suggestion of R. Adler of MRC, we also tested commerically available velvet cloth. This was done by epoxying the cloth to the cathode surface using a conducting silver epoxy. We tested the velvet cathodes in both the flat and convex configurations to compare with the tufted carbon yarn cathodes.

Our experimental configuration consisted of the injector, about two meters of magnetic transport, nine accelerator gaps, and an emittance measuring "box". Our primary diagnostics were the current measuring beam bugs and the optical system that collected the emittance data. After testing the tufted and velvet cathodes using the emittance box, we installed a collimator in the magnetic transport section. This collimator was a water-cooled pipe 106 cm long with a 1 cm radius. The collimator allowed us to measure the beam brightness by measuring the current that was transmitted at a given magnetic field over the collimator.

Definition of Terms

The definition of beam brightness that we use was suggested by Prosnitz and Scharlemann[2] and is given by:

$$J = \frac{\pi^2 \partial^4 I}{\gamma^2 \beta^2 \, \partial V_4} \tag{1}$$

The d^4v term is the four volume of the phase space of the beam. The four volume of a cylindrical magnetic collimator, of radius R, was derived by Sessler[3] and shown to be:

$$V_4 = \frac{\pi^2 K^2 R^4}{6} \tag{2}$$

$$K = \frac{eB}{\gamma \beta mc^2} \quad . \tag{3}$$

Combining Equations 1 and 2, we have the brightness of the beam as a function of the magnetic field over the collimator.

$$J = \frac{6I}{K^2 R^4 \gamma^2 \beta^2} \tag{4}$$

In order to compare our emittance data to the brightness data, we note that if the four volume is ellipsoidal, then

$$V_4 = \frac{\pi^2 \varepsilon_n^2}{2\gamma^2 \beta^2} \tag{5}$$

where ε_n is the normalized edge emittance of the beam.

This leads to an average brightness term given by:

$$J = \frac{2I}{\varepsilon_n^2} \quad . \tag{6}$$

If we assume that the phase space is uniformally filled, then the edge emittance and the rms emittance are related by:

$$\varepsilon_n = 3\varepsilon_{nrms} \quad . \tag{7}$$

The measured values of emittance, ε_m, are taken to be rms values and so the brightness of a beam of emittance ε_n is given by:

$$J = \frac{2I}{9\varepsilon_m^2} \tag{8}$$

Emittance Data

The emittance box consisted of a graphite plate that was range thick to the electrons at this energy (4.4 MeV). The graphite had a regular pattern of 0.051 cm wide slots machined through it and was water cooled to dissipate the heat load. At a distance of 23 cm from the graphite plate, we placed a 0.1 cm thick aluminum foil that had been coated with a fast phosphor on the "downstream" side. We used a water-cooled mirror set at 45 degrees to the beamline to transfer the image of the phosphor screen out of the

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emittance box and into the optical system. The optical system was a gated TV camera and digitizer that stored the emittance data as single frames of TV information.

A single frame of TV data was generated on each shot of the injector. This data was the image of the slot pattern as it appeared on the phosphor screen. Because the emittance box was in a field free region, we could measure the transverse velocity of the beam by directly measuring the increase in the width of the image of the slots.

The measured normalized emittance is given by:

$$\epsilon_m = \theta r \gamma \beta \quad .$$

The angle, θ, is found by taking the half width at half maximum intensity of each slot image and then averaging these angles over the frame. The radius, r, is found by generating a circle that encloses all spot images with an intensity greater than 50% of the maximum intensity of the frame.

All of the tufted carbon yarn cathodes yielded a current of about 10 kA and the normalized rms emittance values ranged from 0.45 to 1.2 rad-cm with an average value of 0.75 rad-cm. This corresponds to a brightness of 3.9×10^3 amps/(rad-cm)^2. The velvet cathodes produced slightly less current (about 9 kA) but the emittance values were considerably lower. The range of values for the velvet cathodes was from 0.16 to 0.41 rad-cm with the average value being 0.25 rad-cm This leads to a brightness of 3.2×10^4 amp/(rad-cm)^2.

It was also noted on using the field emission cathodes that the beam appeared to be very uniform across its diameter and the data were shot-to-shot repeatable. This was clearly not the case with the plasma board cathodes.

Collimator Data

In order to verify the data taken with the emittance box, we installed the collimator in the magnetic transport section. The four solenoidal magnets that surrounded the collimator were on independent power supplies so the field over the collimator was variable. Because the field was created by four discrete magnets, the value of the field had variations, so the value of the field that was used in Equation 4 was an average value for the varying field.

Because we were primarily interested in the velvet cathodes, we took only one data point for the tufted cathodes. Using a flat cathode with 0.13 cm spacing between emission sites (this was the brightest of the tufted cathodes), we transmitted 411 amps through the collimator with an average B-field of 978 gauss. This corresponds to a brightness of $7.3\ 10^3$ amps/(rad-cm)^2.

The velvet cathodes typically transmitted 2000 amps with a B-field of about 1000 gauss. The range in brightness values was from $3.1\ 10^4$ to $4.4\ 10^4$ amps/(rad-cm)^2 with an average value of $3.6\ 10^4$ amps/(rad-cm)^2.

It is interesting to compare the brightness values of the velvet cathodes to the brightness of the plasma board cathodes. Using a different collimator (radius of 2 cm), we found that the maximum current we could transmit with the plasma cathodes was 3000 amps with a B-field of about 1000 gauss. This gives a brightness of 3.3×10^3 amps/(rad-cm)^2 which is an order of magnitude below the velvet cathodes.

Conclusions

Our tests of the field emission cathodes have shown that by using the velvet cathodes, we have improved the brightness of the ATA injector by a factor of ten as compared to the plasma board cathodes.

We have also improved the uniformity of the beam both spatially and temporally and have found the cathodes to be very repeatable on a shot-to-shot basis. Since our tests in the fall of 1984, we have run field emission cathodes exclusively on the ATA injector and we hope to continue brightness experiments with these cathodes in the summer and fall of 1985.

References

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